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PARAMETRIC MODELING AS GEOMETRIC TOOL FOR DESIGNING URBAN MODEL OF BIOMORPHIC FORM INSPIRED BY FLOWER OF BELL FLOWER (CAMPANULA PERSICIFOLIA L.)

Aleksandar A. Čučaković[1], Dragica D. Obratov- Petković[2], Biljana S. Jović[3], Anđela D. Mitić[4]

[1] *Dr., Associate Professor, Faculty of Civil Engineering, University of Belgrade (SERBIA)* cucak@grf.bg.ac.rs
[2] *Dr., Full Professor, Faculty of Forestry, University of Belgrade (SERBIA)* dragica.obratov-petkovic@sfb.bg.ac.rs
[3] *Dr., Docent,. Faculty of Forestry, University of Belgrade (SERBIA)* biljana.jovic@sfb.bg.ac.rs
[4] *MSc., Faculty of Forestry, University of Belgrade (SERBIA)* andjela.mitic182@gmail.com

Abstract

The aim of this research was to apply parametric modeling as appropriate geometric tool in landscape architecture design. Nature model used as inspiration in designing process was flower of the species bell flower (*Campanula persicifolia* L.), which could be found in *Querco-Fagetea* and *Quercetalia pubescentis* forest type. In profession of landscape architecture, this species can be used as a decorative because of its special form of the flower. The applied method of work included three main steps: field research and collection of plant material, generation of a geometric pattern using the geometric methods of Delaunay triangulation and the Voronoi diagram through the 3D Studio Max software and modeling its' biomorphic form that can be combined in different ways giving completely new solutions. Biomorphic form of the flower of selected species was obtained by using different vertexes as parameters in design modeling process. Parametric modeling today is an integral part of every 3D modeling software. This type of modeling involves defining and manipulating specific parameters that defines a created model. Result of this parametric modeling method was conceptual urban design model - bench. Some of new trends that designing urban spaces seeks is creating sustainable urban environment that strengthens the connection between people and nature in domains of aesthetics. This new and innovative urban element of public space could be the part of the new approach towards sustainable urban design.

Keywords: Bell flower (*Campanula persicifolia* L.), Delaunay triangulation, Voronoi pattern, 3D Studio Max, biomorphic form, urban design model.

1 INTRODUCTION

Nature provides an inexhaustible inspiration source for any design profession. Its patterns are recognized as a forms of visual harmony and they are studied primarily through geometrical principles and models in areas of art and design. The frequency of their repetition is characterized by the patterns itself. But also, each pattern is inclined to changes and modifications in order to achieve the flexibility that makes them sustainable and timeless. From the tiniest to the spatial, natural patterns can be recognized in DNA structure, nervature of the leaf or interesting print of the bodies of some animals. Nature's geometric patterns may be one of the first natural rules who are recognizable by people. The integration of natural patterns into design processes could be achieved with the help of different digital software. With advances in using different software based on parametric modeling through the design process, the uses of biomorphic forms were enabled. Biomorphic forms, as visible patterns of nature, represents different contours, textures, structures and shapes that we could find hidden in our environment. Nature forms, and its simplicity and complexity in the same time, have inspired for many centuries various artists, scientists and inventors like Leonardo di Piero da Vinci or Michelangelo di Lodovico Buonarroti Simoni. Famous biologist and mathematician D'Arcy Thompson considered that the form of an object represents a diagram of different forces that played an important role in its emergence.

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2 BIOMORPHIC FORMS AS PART OF PARAMETRIC DESIGN

Natural forms represent the individual results of a self-generative process which is unique to every species for itself [1]. According to Gruber, biomorphology is a science of construction and of the organization of living things and their components [2]. Biomorphic forms represent an aesthetics form which comes from complex but organized geometries in nature. The term biomorphism is composed of the Greek words: βίος which means life, living, and μορφή which represents form. Biomorphism has been often associated with organic shapes, forms and patterns in art, architecture, landscape architecture and design [3]. The use of biomorphic forms in different design solutions isn't new. Works of a famous architect Antonio Gaudi, represents the use of organic, biomorphic forms in architectural design. Demonstrated in buildings such as Casa Mila, Guell park and Sagrada Familia in Barcelona, Gaudi's work exudes a vibrant life through its organic structure derived from observation of nature. Buildings with biomorphic forms as design elements continued with the work of Kendrick Bangs Kellogg. His works such as the Lotus House - with the roof with integral solar water heated panels that looks like the petals of a flower, High Desert Home or Joshua Tree House and Onion House Kona Hawaii, represents biomorphic form at the best way [1]. The spectrum of natural structures that can be used as inspiration of biomorphic form has expanded from just floral structures used in design. Various plants have been used as role models ever since man began to use technology. Still, the elegance of flowers and its basic form and structure which is established on minimal geometric shapes, was used as inspiration for several building design. Next to Lotus House by Kellogg, there is the Lotus Temple - Bahá'í House of Worship, located in New Delhi in India (Fig. 1). The House of Worship is composed of 27 free-standing marble-clad petals of lotus flower arranged in clusters [4]. In landscape architecture, biomorphic forms could be found in works of Roberto Burle Marx, famous landscape architect from Brazil. He participated in the development of Brazil's city plan next to Lucia Boats, urban planner and Oscar Nimaier, city architect. The city is constructed in the shape of a bird wings that are clearly visible from the bird's eye view. The inspiration for his second big project - the beach promenade at Copacabana in Rio de Janeiro (Fig. 2) was the meandering river of Brazil [5]. Stephen Todd and William Latham have explored the use of algorithms to generate biomorphic forms, which incorporate free-flowing curves. Together, they developed biological forms that range from organisms found in nature to any biomorphic form imagined just utilizing the geometric principles from nature and the algorithmic processes. The main subject of their process was visual observation of the generated form and editing of either the parametric variables or the generative structure of the algorithm [1].

Fig. 1. The Lotus Temple - Bahá'í House of Worship, Kendrick B. Kellogg (source: https://commons.wikimedia.org/wiki)

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Fig. 2. The beach promenade at Copacabana in Rio de Janeiro, Roberto B. Marx (source: https://commons.wikimedia.org/wiki)

Natural patterns organize and define relations in nature and they can be integrated into design with different digital technologies. Modeling, as a creative process connected with design, results in creating a desired model. Software based on parametric modeling is also called 3D modeling software because they use three dimensions: length, width, and height (3 axes: x - horizontal axis, y - vertical and z - height). This kind of modeling involves defining and manipulating specific parameters. Parameters represent constant sizes in some mathematical function. Every complex model or form can be created by using simple geometric models to construct and be modified by changing the various parameters within the software [4]. Thanks to these characteristics, parametric models are easy and flexible to operate with. Parametric designs or models, as a result of parametric modeling, are innovative and original models [6][7]. This model becomes a new medium of experience, exploration and learning revealing different level of complexities and dimensions. The unique model has been determined by parameters that describe the model and parameters that are employed to generate the model. These changing parameters represents form finding design process of exploring the nature of parametric modelling [8]. The example of parametric model with a suitable form of Voronoi pattern is Natalie's Ramonda pavilion model (Fig. 3) [6].

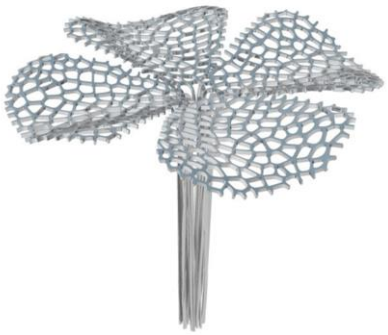

Fig. 3. Natalie's Ramonda pavilion, Jović, Komnenov, 2017.

Parametric modelling has become an integral part of the landscape and architectural design process. This kind of modelling contributes to design process and is becoming more and more transdisciplinary. The design process becomes an interactive, resulting in more complex and original parametric design models. This parametric model goes far beyond forms, and they are the results of better understanding of natural forces and phenomena [8]. Designing according to natural principles seeks to use the properties of living structures, forms and energies that exist or act in nature in order to balance the various processes and that unity of structure and aesthetics of forms represents new source of endless inspiration [9]. Parametric modelling is the appropriate geometric tool for reading and generating biomorphic forms as well as for its modelling in the desired structures and elements that could be presented into the physical world. Thanks to parametric modeling, it is possible to generate and manipulate a multitude of different structures and explore different geometric forms, as well as many natural patterns and biomorphic forms.

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3 MATERIALS & METHODS

The method of work included field research and collection of plant material of bell flower (*Campanula persicifolia* L.), generation of a geometric pattern using the geometric methods of Delaunay triangulation and the Voronoi diagram through the 3D Studio Max software and modeling its' biomorphic form.

3.1 Inspiration found in Bell flower *Campanula persicifolia* L.

The first step in this research was choosing the appropriate model from nature. The species selected as an appropriate model was bell flower, a herbaceous perennial plant, height up to 1 meter. *This plant, from* Campanulaceae family, was described for the first time in 1753. by Linnaeus. Professor Josif Pančić described it in 1874. and included it in the Principality of Flora in Serbia. This species grows from the plain to the alpine belt and have a Mediterranean origin, prefers neutral or limestone soils from pH 6.1 to 7.5, sunny and partial shade places. It can be found in *Querco-Fagetea and Quercetalia pubescentis* forest types*.* Flower period is in April and May. In the landscape architecture, bell flower could be used as a decorative plant, because of a specific bell form of flower. The bell flower is distributed in whole Europe, Siberia and Armenia. In Serbia is well distributed too. Field research at Avala site, near Belgrade, and collection of plant material was conducted on May 27, 2017. in order to collect plant material for further investigation. The collected plant material is herbarized [10].

The bell flower is a perennial herb with simple and upright stem with rare leaves. The lower leaves are elongated, narrowed, while the upper leaves are smaller, linear spear, roaded and sharp at the top. Leaves that are on the middle of the stem are striped or striped-spinning and road, wide 2-8 mm and with a curved edge. The flowers are in the shorter petioles in the raceme inflorescence. The sepals are with lanceolate teeth and the petals are wide, bell shape with ovate teeth and a steeple at the end. Blue or nuances blue and purple is the colour of the petals (Fig. 4). They are as long as the sepals, and the stamp is triangular [10].

Fig. 4. Flower of bell flower (Campanula persicifolia L.); *(Author: Mitić)*

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3.2 Voronoi diagram and Delaunay triangulation as geometric methods for generating biomorphic form

In order to generate the biomorphic form that could be used in design process, in this research was used geometric methods of Delaunay triangulation and the Voronoi diagram. Delaunay triangulation represents a unique triangulation, a set of points and edges that meet the requirement of "empty circle". The Delaunay triangle does not have missed points. This method is connected with Voronoi diagram method in the way in which the possibility of a line connecting two vertices of Voronoi diagram, provided that the edge between two Voronoi polygons is shared, and it's marked as a dual structure of the Voronoi diagram – Delaunay triangulation [4]. Voronoi diagram (Voronoi Georgi, Russian mathematician) is a geometrical concept and graphical representation of objects or points, in which their mutual distances form a geometric pattern [11]. The Voronoi geometry is an organizational phenomena that re-occurs at a variety of scales, materials, and life forms. Different examples could be found in biology, mineralogy of formation principles geometry, and construction such as foams, sponges, bone structures and crystals [12]. Voronoi diagrams could be found in nature in a form of a white flower (*Bellis perennis* L.), a species *Prunus domestica* L. with mosaic nervature of leaf, or honeycomb and else. The Voronoi diagram has wide application in different domains. In urbanism it is used to define the position of important objects. It is also used in biology to determine the area of land used by certain plant species [13].

Construction of the Delaunay triangulation and Voronoi Diagram consists of five steps. First step was marking of the starting points, the triangular network trim or Voronoi points, specific of a particular pattern. Further, constructing Delaunay triangulation by joining the closest neighbor's points in the longitudinal direction, without cutting off the joints, and determination half of the line segment - determination of the half edges of the Delaunay triangulation. The construction of the normal direction at the point of the spin and the determination of their point intersection is the next step - represents the center of the circumscribed circle of the triangle. Formation of the Voronoi diagrams in which Voronoi points are located at the shortest distance from the edges of the Voronoi polygon is the final step - drawing lines per normal of Voronoi diagrams to obtain closed fields with vertices that are centers of circles described triangles of Delaunay triangulation [13].

3.3 NURBS elements – parametric object for modelling of biomorphic forms

Today, every design process almost inevitably includes a parametric modelling. Every complex model or form could be constructed and modified using simple geometric models by changing the various parameters within the software. Every parametric design model, as a result of parametric modelling, could be innovative and original. As an important part of the design process, parametric modelling represents an appropriate geometric tool for generating geometric pattern of plant species bell flower, as well as for modelling structures into elements of biomorphic forms. In this research, AutoDesk 3D Studio Max software was chosen for generating biomorphic form of the species bell flower and parametric modelling process for creating an urban model of bench. 3D Studio Max is professional 3D computer software for creating 3D animations, models or images. This software found its application in architecture, landscape architecture, game design, visualization and other areas. Parametric modelling is a main part of almost every 3D modelling software, and also 3D Studio Max. 3ds Studio Max uses the concept of modifiers and parameters to control its geometry objects. Geometric objects that could be constructed in 3ds Studio Max could be divided in two basic types of models: parametrical and parametrical constructed edited objects (Editable). Parametric objects are changeable because of the change of parameters that define them, which makes them flexible. Edited objects have special features for editing and include curves (Editable splines), networks (Mesh), polygons (Poly) and other objects.

A geometric pattern of plant species was generated using geometric methods of Delaunay triangulation and the Voronoi diagram. The comprehensive Voronoi structure is derived by applying AutoDesk 3D Studio Max software and using its appropriate components: modifiers and parameters. With this software, the arrangement of manually drawn points is translated into a form whose structure corresponds to the surface of the flower petal of bell flower. The basic parametric design tools within the software package allow us to manipulate and modify the object and its morphological characteristics of form until the desired result is achieved.

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The modelling process included an import of selected image on which has been applied mentioned geometric methods. Computer aided design (CAD) software is used to create computational geometry models. In CAD the data models or geometric objects are described by non-uniform rational B-splines [14]. Within a computer-based design process, for the modeling was chosen non-uniform rational basis splines (B-splines), known as NURBS. This geometrical model is commonly used in computer graphics for generating curves and surfaces. NURBS tool was ideal for generating free-form geometry of the flower of selected plant species. The first step of the modelling process involved importing photos and plotting the form of petals of bell flower using NURBS Surface: on the constructed Plane was imported photo as material in Modify segment and the form of flower petal was created using NURBS Surfaces (Fig. 5). In the process, it was possible to manually change the parameters of created points of the NURBS Surface, move or add additional points to future Voronoi cells (Vertexs). Adjusting parameters as length and width of the points, and same advanced parameters as the Low Tessellation Method Delaunay Subdivision Style creates the desired form of flower petals (Fig. 6).

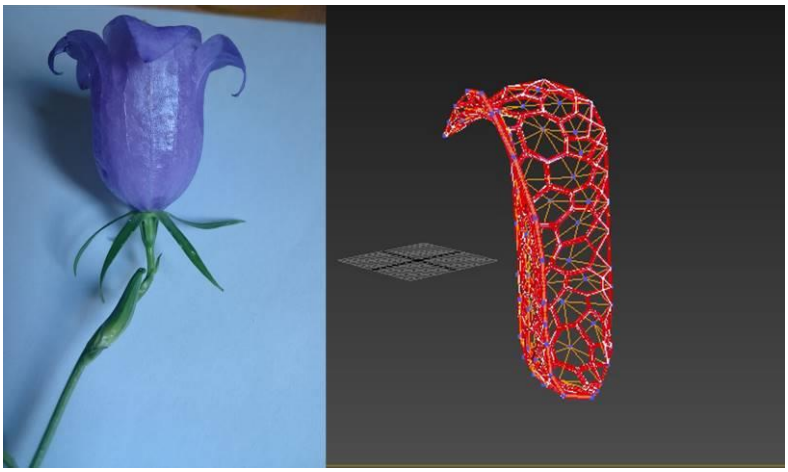

Fig. 5. The form of petals of bell flower using NURBS Surface (Author: Mitić)

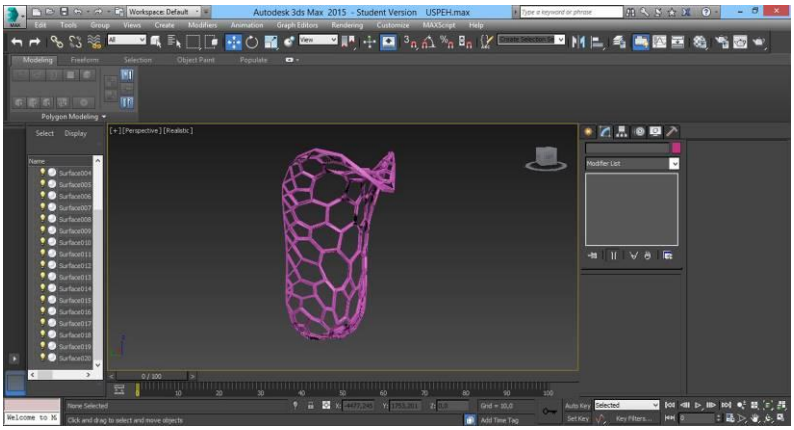

Fig. 6. The biomorphic form of petal of bell flower (Author: Mitić)

The next step involved the use of the Voronoi method. In this step of modelling process were used special modifiers of 3D Studio Max software. In this way were construct Voronoi diagrams and by custom desire, we modified the thickness and other parameters of the model with biomorphic form. Some other modifiers were used for reinforcement of the construction of the Voronoi diagram. The final steps involved defining the grid (model was converted into the grid) and the finishing the model of urban element - bench.

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4 RESULTS

Based on petal of bell flower and using the modifiers and its parameters of 3D Studio Max software in process of parametric modelling, the result of this research was conceptual design of urban element with biomorphic form. Its' biomorphic form could be combined in different ways giving completely new solutions of urban elements. Biomorphic form of the flower of selected species, obtained by using different vertexes as parameters in design modelling process, represents a new aesthetical experience in urban space. The construction of urban design model was presented in the form of a 3D model of bench (Fig. 7). This unique urban design model could represent a new, innovative and attractive element of every urban space (Fig. 8).

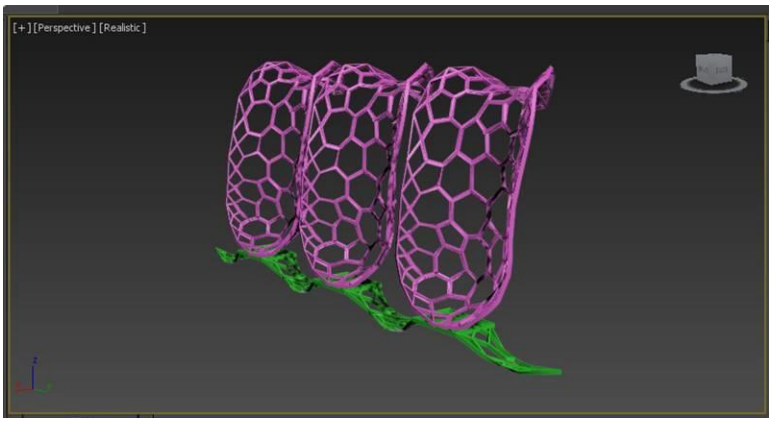

Fig. 7. 3D model of bench (Author: Mitić)

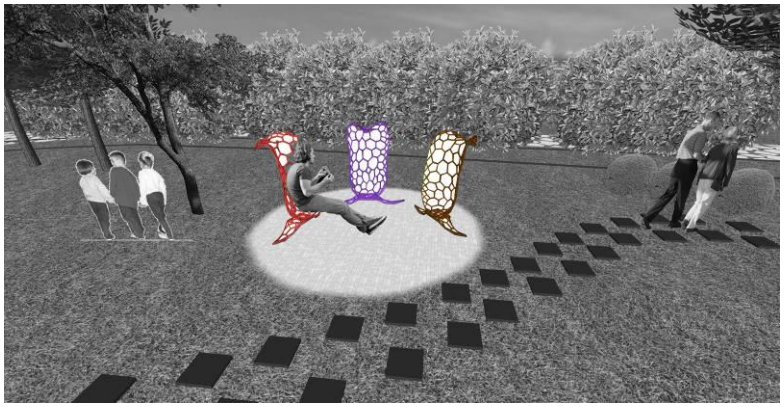

Fig. 8. The design model of bench in urban space (Author: Mitić)

5 CONCLUSION

Patterns present in nature represent the fundamental characteristics of each space. Different professions explore the space, whether it's a landscape architecture, architecture, urban planning, or spatial planning, they study different spatial patterns that could be used in the design process. The aim of this research was to present the application of the parametric modelling in the design process on the case of generating and modelling different biomorphic forms within the landscape architecture. The parametric modelling, as an important part of the landscape architectural design process, is the appropriate geometric tool for reading and generating natural patterns and forms, as was shown in this research. The geometric methods such as Delaunay triangulation and Voronoi diagrams have proved to be excellent methods in design process for generating biomorphic form of bell flower. First step were finding appropriate nature model, conduct field research and collection of plant material. The generation and modeling process of selected plant species using the geometric methods of Delaunay triangulation and the Voronoi diagram through the 3D Studio Max software were next step included in the research. Final step was modelling process of its' biomorphic form that can be modified in different ways giving completely new and original design solutions. The result of this parametric modeling method was conceptual urban design model - bench.

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Driven by parametric modeling tools, the landscape architectural designs are pushing boundaries of form, customization and construction in all aspects of the profession. Integration of parametric modeling into designing process could be a promising direction for the further development of landscape architecture. The positive effects of including biomorphic design in landscape architectural profession are, first of all, new and innovative design methodology that has the big potential for exploring design on a completely new ways. Developing innovative solutions and design-based research based on inspirations found in nature also represents a natural connection between biology and design that gets its form in landscape architecture. There are many ways in which nature could influence design and its end models and forms. These free-flowing forms are new and innovative and could represents an attractive elements of urban space. Creating new urban environments that strengthens the connection between people and nature is a new challenge in designing an urban spaces. This new and original urban design model of public space could be new direction towards naturally inspired urban design.

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